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PAPER

Energy density of diets reported by American adults: association with food group intake, nutrient intake, and body weight

AK Kant[1]* and BI Graubard[2]

[1]*Department of Family, Nutrition, and Exercise Sciences, Queens College of the City University of New York, Flushing, NY, USA; and* [2]*Division of Cancer Epidemiology and Genetics, Biostatistics Branch, National Cancer Institute, National Institutes of Health, Bethesda, MD, USA*

OBJECTIVE: Recent reports suggest that dietary energy density may play a role in regulation of food intake. However, little is known about the energy density of diets consumed by free-living populations; therefore, the purpose of this study was to examine demographic, health, and nutritional correlates of energy density of self-reported diets.
RESEARCH METHODS AND PROCEDURES: Using data from the NHANES III ($n=13\,400$), dietary energy density was defined three ways: (1) energy content (kJ/g) of all foods and beverages reported or ED1, (2) energy content (kJ/g) of all foods and energy yielding beverages or ED2, and (3) energy content (kJ/g) of all foods (no beverages) or ED3. Multiple linear or logistic regression methods were used to examine the association of energy density with intake of energy, nutrients, food groups, and body mass index (BMI). We computed the ratios of within- to between-person variance for the three energy density variables using the second recall obtained from the second exam subsample of NHANES III ($n=1037$).
RESULTS: The mean ED1, ED2, and ED3, respectively, were 3.84 ± 0.02, 5.45 ± 0.03, and 8.03 ± 0.03. Dietary intakes of energy, fat, and low-nutrient-density foods were related positively, but amounts of micronutrients, fruit, and vegetables were related inversely with all types of energy density ($P<0.0001$). ED2 and ED3 were modest positive predictors of BMI in both men and women ($P\leq0.03$). The ratios of within- to between-person components of variance for ED1, ED2, and ED3 were 1.34, 2.05, and 1.53, respectively.
DISCUSSION: High-energy-density diets in the US were characterized by low fruit and vegetable intake, and high BMI.
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Keywords: NHANES III; energy-density; food group intake; body mass index; components of variance; nutrition survey

Introduction

Several recent reports have suggested that dietary energy density may play a role in regulation of food intake.[1–3] In short-term experimental studies involving manipulation of energy density, subjects fail to compensate for changes in energy density by altering the volume of food consumed, resulting in higher energy intake (EI) when test meals were higher in energy density.[1–3] There is some evidence that the effect of energy density may be independent of the macronutrient composition of the diet.[1,4,5] Finally, it has been suggested that the satiety and satiation effects of diets of high energy density may be lower relative to diets of low energy density.[6] Given the potential role of energy density in contributing to higher EIs and subsequent positive energy balance, surprisingly little is known about energy density of self-reported diets in free-living populations.[1,2,7,8]

The objective of the present study was to examine the socio-demographic, nutritional, and health correlates of energy density of diets reported by a representative sample of the US population. However, as pointed out by Cox and Mela,[9] there is no consensus about the definition of energy density in the published literature. Different investigators operationalize energy density in various ways resulting in differing results. The association of energy density with dietary and subject profiles has been shown to vary with the method used for calculation of energy density.[9] Exclusion of all beverages or low-energy beverages with their potential

*Correspondence: Professor AK Kant, Department of Family, Nutrition, and Exercise Sciences, Remsen Hall, Room 306E, Queens College of the City University of New York, Flushing, NY 11367, USA.
E-mail: akant@qc.edu
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dilutional effect may be one of the most influential factors responsible for differing estimates of food based energy density.[9] With these considerations, an additional objective of this study was to examine the association of dietary and subject characteristics with energy density computed from methods that differed due to exclusion of beverages. Lastly, we examined the within- and between-person components of variance contributing to variability in energy density computed from different methods, which are useful for understanding dietary reporting patterns and for correcting for random measurement error in the reporting of energy density.

Methods

This study used data from the third National Health and Nutrition Examination Survey (NHANES III), 1988–1994. The NHANES III was a multistage stratified probability sample of the noninstitutionalized, civilian US population, aged 2 months and over.[10] The survey was conducted by the National Center for Health Statistics (NCHS), and included administration of a questionnaire at home and a full medical exam along with a battery of tests in a special mobile examination center (MEC). Demographic and medical history information was obtained during the household interview. The MEC exam included a physical and dental exam, dietary interview, body measurements, and collection of blood and urine samples. Body weight and height were measured using standardized procedures in the MEC.

Dietary assessment method

A 24-hour dietary recall was collected by a trained dietary interviewer in a MEC interview using an automated, microcomputer based interview and coding system.[10] The type and amount of foods consumed were recalled using aids such as abstract food models, special charts, measuring cups, and rulers to help in quantifying the amounts consumed. Special probes were used to help recall commonly forgotten items such as condiments, accompaniments, fast foods, and alcoholic beverages, etc. The recall included all foods, beverages and bottled water (but not plain drinking water).

As part of a substudy within NHANES III, a nonrandom subsample of approximately 5% of those who completed a visit to the MEC was invited back for a second visit.[11] During this repeat visit, another dietary recall, using methods similar to the first one, was also obtained.

Analytic sample

All examined adults aged 20 y and over were eligible for inclusion ($n = 17\,030$) in this study. A complete and reliable dietary recall (as determined by NCHS) was not available for 1051 respondents, leaving 15 979 eligible for inclusion. We further excluded respondents stating that food intake on recalled day was 'much less' or 'much more' than usual ($n = 2245$), women who were pregnant ($n = 282$) or nursing ($n = 91$), and those missing information on body weight ($n = 33$) or height ($n = 16$). Some respondents were in more than one exclusion category. The final analytic sample included 13 400 respondents (6452 men and 6948 women). From the second exam subsample, a reliable second recall was available for 1037 respondents who also provided a reliable first recall.

Assessment of energy density

Due to lack of a consensus about definition of energy density in the published literature, for this study, energy density was operationalized three ways: (1) energy content (kJ/g) of all foods and beverages reported or ED1, (2) energy content (kJ/g) of all foods and energy yielding beverages or ED2, and (3) energy content (kJ/g) of all foods (no beverages) or ED3.

As a first step in computation of energy density variables, all foods reported by $\geq$20-y-old respondents in the NHANES III were grouped into beverage or nonbeverage categories. For the purpose of this study, all carbonated and noncarbonated drinks including sodas and fruit juices, coffee and tea, alcoholic drinks, water, milk or milk-based drinks, etc, were considered as beverages. Beverages with $<$10 kcals/100 g (diet drinks) were excluded from computing the ED2 variable.

Assessment of nutrient and food group intake

The NHANES III nutrient database for individual foods, which is derived from the US Department of Agriculture's Survey Nutrient Database, was used to determine energy, and nutrient content of all foods. The nutrients examined included macronutrients, dietary fiber, and several micronutrients (carotenoids, vitamins C, B_6, and folate, and the minerals iron and calcium). As amount and nature of foods consumed provides additional information about food selection behaviors in relation to energy density of foods selected, we also estimated the intake of foods from the five major food groups and low-nutrient-density foods using methods described previously.[12]

As an estimate of possible low energy reporting, a ratio of reported EI to energy expenditure for basal needs (BEE) was also computed. BEE was estimated using age–sex–weight specific equations developed by the DRI committee.[13] We used an EI:BEE ratio of $<$1.2 to suggest low-energy reporting in this study.

Statistical analyses

The mean 24-h intakes of energy, amount of macro- and micronutrients, amount of foods from the five food groups, and low-nutrient-density foods were obtained by (sample) weighted tertiles of each type of energy density using regression models adjusted for a number of covariates. All covariates included in the various multiple regression models were decided *a priori* based on known relationships of socio-demographic, and lifestyle factors with body weight and dietary reporting. The estimates of nutrient and food group intake were adjusted for age, race (non-Hispanic White, non-Hispanic Black, Mexican-American, other), years of education, smoking status (never, former, current), level of weekly recreational physical activity (none, 1–2 times/week, >2 times/week), self-reported history of diabetes, hypertension, or heart disease (yes, or no), and body mass index (BMI) (continuous), whether trying to lose weight at the time of survey (yes, or no), and EI. All statistical analyses were performed using SAS,[14] and software designed for analysis of survey data (SUDAAN).[15] This software generates variance estimates that are corrected for multistage stratified cluster probability design of complex surveys. Sample weights provided by the NCHS to correct for differential probabilities of selection, noncoverage, and nonresponse were used in all analyses to obtain point estimates.[9,16]

The independent association of energy density with BMI, and intake of foods and nutrients was examined using regression procedures to adjust for multiple covariates mentioned above. Linear regression procedures were used when the outcome variables were continuous (eg, dietary nutrient intake). For categorical outcomes such as a dichotomous BMI variable (<25 or ≥25), we used logistic regression procedures.

From the second dietary recall obtained from the second exam subsample for NHANES III, we computed within- and between-person components of variance for each type of energy density and amounts of foods and beverages reported, using the varcomp procedure available in SAS. We applied a standard correction to the energy density regression coefficient from the multiple linear regression of BMI to adjust for nondifferential independent measurement error in energy density.[17] This correction uses un-(sample)-weighted estimates of covariate-adjusted within- and between-person variances of the regression of energy density, which were obtained using the second exam subsample.

Results

The mean ED1 and ED3 were higher in men than women, but mean ED2 was higher in women (Table 1). Respondents aged ≤50 y reported diets of higher ED1 and ED3 relative to those >50 y. Respondents with higher BMI reported higher ED2 and ED3, but ED1 varied little by BMI categories.

The reported amounts (g) of all foods and beverages were related inversely with all three energy density variables (Table 2). The reported amounts of fruits and vegetables decreased, and grams of added fat increased in association with the three energy density variables (Table 3). ED2 and ED3 related inversely with amount of foods and beverages from the five major food groups but positively with amounts of low-nutrient-density foods. The intake of added sugars increased with increasing ED1 and ED3, but decreased with ED2.

The mean energy, and energy-adjusted grams of fat and saturated fat were positively related with each type of energy density (Table 3). Grams of protein, carbohydrate, fiber, and all examined micronutrients were related inversely with each type of energy density. The steepest slopes were seen for the association of ED1 with EI, and ED3 with micronutrient intake.

Table 4 shows the socio-demographic characteristics of respondents in tertiles of ED1, ED2, and ED3. A higher proportion of respondents self-reporting chronic diseases and attempting weight loss were in lower tertiles of ED1 and ED3. A higher proportion of respondents in the first tertile of ED1 considered themselves overweight. The percentage of

Table 1 Least-squares mean ± s.e. energy density (ED) (kJ/g) reported in the NHANES III

	ED 1 (kJ/g of all foods & beverages)			*ED 2 (kJ/g of foods & energy yielding beverages)*			*ED 3 (kJ/g of foods only)*		
	All	*Men*	*Women*	*All*	*Men*	*Women*	*All*	*Men*	*Women*
All ages	3.84 ± 0.02	3.95 ± 0.03	3.74 ± 0.02	5.45 ± 0.03	5.41 ± 0.03	5.49 ± 0.06	8.03 ± 0.03	8.30 ± 0.05	7.75 ± 0.04
≤50 y	3.98 ± 0.02	4.04 ± 0.03	3.92 ± 0.03	5.47 ± 0.04	5.36 ± 0.05	5.58 ± 0.06	8.50 ± 0.05	8.67 ± 0.07	8.33 ± 0.06
>50 y	3.60 ± 0.02	3.78 ± 0.03	3.44 ± 0.04	5.42 ± 0.05	5.53 ± 0.06	5.34 ± 0.06	7.20 ± 0.05	7.59 ± 0.06	6.86 ± 0.07
Non-Hispanic White	3.73 ± 0.02	3.85 ± 0.03	3.61 ± 0.03	5.51 ± 0.04	5.48 ± 0.04	5.42 ± 0.07	8.17 ± 0.04	8.49 ± 0.06	7.86 ± 0.05
Non-Hispanic Black	4.53 ± 0.03	4.68 ± 0.04	4.39 ± 0.04	5.46 ± 0.04	5.50 ± 0.05	5.19 ± 0.09	8.22 ± 0.07	8.41 ± 0.07	8.02 ± 0.09
Mexican-American	3.99 ± 0.03	4.06 ± 0.04	3.95 ± 0.04	5.07 ± 0.06	4.96 ± 0.05	5.28 ± 0.13	7.45 ± 0.08	7.68 ± 0.08	7.26 ± 0.11
Other	4.06 ± 0.08	4.10 ± 0.09	4.01 ± 0.13	5.11 ± 0.07	4.92 ± 0.11	5.53 ± 0.05	6.73 ± 0.13	6.73 ± 0.17	6.74 ± 0.15
BMI <25 kg/m^2	3.89 ± 0.02	4.01 ± 0.04	3.77 ± 0.03	5.36 ± 0.04	5.28 ± 0.05	5.41 ± 0.05	7.91 ± 0.06	8.15 ± 0.07	7.70 ± 0.08
BMI 25–29.9 kg/m^2	3.79 ± 0.03	3.93 ± 0.04	3.65 ± 0.05	5.47 ± 0.04	5.44 ± 0.06	5.48 ± 0.07	8.03 ± 0.05	8.33 ± 0.07	7.73 ± 0.08
BMI >29.9 kg/m^2	3.83 ± 0.03	3.89 ± 0.05	3.75 ± 0.05	5.62 ± 0.06	5.61 ± 0.10	5.64 ± 0.07	8.27 ± 0.07	8.57 ± 0.11	7.97 ± 0.07

Least-squares means from regression models with energy density as a continuous outcome and age, gender, race/ethnicity, level of education, smoking status, level of physical activity, body mass index, currently trying to lose weight, and history of disease, as independent variables. Respondents with missing information on a covariate were excluded (n = 13017, 6252 men, and 6765 women).

Table 2 Least-squares mean ± s.e. of amount of food (g) reported by tertiles of energy density (ED) (kJ/g). NHANES III, 1988–1994

	ED 1 (kJ/g of all foods & beverages)			ED 2 (kJ/g of foods & energy yielding beverages)			ED 3 (kJ/g of foods only)		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
Mean ED	2.57	3.71	5.36	3.7	5.1	7.4	5.4	7.7	10.8
N	3829	4523	5048	4716	4595	4089	4746	4524	4130
Amt. of beverages (g)	2113 ± 40	1497 ± 18	1000 ± 19	1823 ± 29	1441 ± 29	1349 ± 21	1395 ± 25	1547 ± 25	1668 ± 28
Amt. of foods & beverages from the five food groups (g)	1071 ± 15	1176 ± 16	1107 ± 16	1239 ± 18	1189 ± 18	930 ± 10	1359 ± 15	1152 ± 19	846 ± 12
Amt. of fruits & juices (g)	176 ± 5	174 ± 8	143 ± 5	215 ± 7	178 ± 6	100 ± 4	246 ± 6	152 ± 5	96 ± 5
Amt. of vegetables & juices (g)	289 ± 6	291 ± 6	252 ± 6	325 ± 6	284 ± 5	223 ± 5	404 ± 8	278 ± 4	150 ± 4
Amt. of grains (g)[a]	197 ± 4	235 ± 5	240 ± 5	220 ± 5	236 ± 5	217 ± 5	260 ± 5	233 ± 6	180 ± 3
Amt. of dairy foods & beverages (g)[b]	221 ± 8	251 ± 10	234 ± 9	284 ± 12	262 ± 11	161 ± 5	234 ± 6	250 ± 11	222 ± 7
Amt. of meat & alternates (g)	186 ± 4	227 ± 5	242 ± 5	195 ± 5	231 ± 4	229 ± 5	215 ± 5	242 ± 5	199 ± 5
Amt. of low-nutrient density foods & bevs. (g)	1658 ± 47	1140 ± 15	862 ± 18	1177 ± 30	1174 ± 27	1309 ± 22	1067 ± 22	1219 ± 24	1372 ± 31
Added fat (g)	45 ± 1.0	63 ± 0.9	81 ± 1.6	47 ± 0.9	65 ± 1.0	76 ± 1.2	47 ± 0.9	66 ± 1.0	76 ± 1.0
Added sugar (tsp)	17 ± 0.6	21 ± 0.5	22 ± 0.4	20 ± 0.6	20 ± 0.5	18 ± 0.4	16 ± 0.5	20 ± 0.4	24 ± 0.6

Least-squares means from regression models adjusted for age, gender, race/ethnicity, level of education, smoking status, level of physical activity, body mass index (continuous), currently trying to lose weight (yes, no), history of disease (diabetes, hypertension, and MI), and energy intake (kcals). Models for energy did not include energy. Respondents with missing information on a covariate were excluded ($n = 13017$; 6252 men and 6765 women). Unless noted otherwise, the overall F test for heterogeneity of amounts reported among tertiles of energy density was significant ($P \leq 0.004$). [a]The overall F test for heterogeneity of amounts reported among tertiles of ED2 was significant at $P = 0.02$. [b]The overall F test for heterogeneity of amounts reported among tertiles of ED1 was significant at $P = 0.03$; for ED3, $P = 0.05$.

Table 3 Least-squares mean ± s.e. of energy and nutrient intake by tertiles of energy density (ED) (kJ/g). NHANES III, 1988–1994

	ED 1 (kJ/g of all foods & beverages)			ED 2 (kJ/g of foods & energy yielding beverages)			ED 3 (kJ/g of foods only)		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
Energy (kcal)	1828 ± 21	2221 ± 23	2523 ± 35	2008 ± 27	2244 ± 24	2317 ± 24	1912 ± 22	2277 ± 27	2380 ± 25
Fat (g)	76 ± 0.8	82 ± 0.6	94 ± 0.9	71 ± 0.6	85 ± 0.5	96 ± 0.8	74 ± 0.7	85 ± 0.7	93 ± 0.5
SFA (g)	25 ± 0.3	28 ± 0.3	31 ± 0.4	24 ± 0.3	29 ± 0.3	32 ± 0.4	25 ± 0.3	29 ± 0.3	31 ± 0.3
Protein (g)	84 ± 1.0	84 ± 0.7	81 ± 0.7	83 ± 0.8	84 ± 0.7	81 ± 0.9	89 ± 0.9	85 ± 0.7	75 ± 0.8
CHO (g)	273 ± 3	270 ± 2	255 ± 2	284 ± 3	269 ± 2	245 ± 2	282 ± 3	261 ± 2	255 ± 2
Alcohol (g)	16 ± 1	10 ± 0.7	4 ± 0.9	17 ± 1	16 ± 0.6	7 ± 0.8	11 ± 0.1	11 ± 1	9 ± 1
Fiber (g)	18 ± 0.2	18 ± 0.2	16 ± 0.2	18 ± 0.2	17 ± 0.2	16 ± 0.2	21 ± 0.2	17 ± 0.2	13 ± 0.1
Folate (μg)	323 ± 6	301 ± 4	252 ± 4	331 ± 5	299 ± 5	246 ± 4	346 ± 5	298 ± 5	233 ± 3
Vit. C (mg)	125 ± 4	112 ± 2	84 ± 2	137 ± 3	111 ± 2	71 ± 2	153 ± 3	102 ± 2	66 ± 2
Carotenoids (μg RE)	642 ± 23	574 ± 18	423 ± 22	688 ± 23	569 ± 20	383 ± 18	891 ± 27	549 ± 20	203 ± 10
Vit. B_6 (mg)	2.1 ± 0.03	2.0 ± 0.03	1.7 ± 0.02	2.1 ± 0.03	2.0 ± 0.02	1.7 ± 0.02	2.3 ± 0.03	1.9 ± 0.02	1.6 ± 0.02
Calcium (mg)	876 ± 13	853 ± 12	788 ± 12	898 ± 15	869 ± 14	750 ± 7	894 ± 14	846 ± 12	777 ± 9
Iron (mg)	16 ± 0.3	16 ± 0.3	15 ± 0.2	17 ± 0.3	16 ± 0.2	15 ± 0.2	17 ± 0.2	16 ± 0.3	14 ± 0.4

Least-squares means from regression models adjusted for age, gender, race/ethnicity, level of education, smoking status, level of physical activity, body mass index, currently trying to lose weight, history of disease, and energy intake. Models for energy did not include energy. Respondents with missing information on a covariate were excluded ($n = 13017$; 6252 men, and 6765 women).The trend for the independent association of each energy density variable and nutrients in the table (except protein and alcohol) was significant ($P < 0.0001$). The association of ED1 and ED2 and grams of protein was significant at $P = 0.006$ and 0.04, respectively, and ED3 association with gram of alcohol was not significant ($P > 0.05$).

respondents with EI/BEE of <1.2 was higher in the first tertile of each type of energy density.

The association of ED1 and BMI was not significant and the regression coefficient was negative in men (Table 5). ED2 and ED3 were modest positive predictors of BMI in both men and women. The odds of having a BMI of $\geq 25\,kg/m^2$ were significantly higher ($P = 0.02$) for men and women in the third tertile of ED3. Addition of EI to these models did not change the association of ED2 and ED3 with BMI. Correction of regression coefficients associated with energy density for measurement error resulted in large increases (three- or four-fold) in both the coefficient and its standard error (Table 5 shows deattenuated regression coefficients).

The ratios of within-to between-person components of variance for the three energy density variables were greater than one, and the ratio was highest for the ED2 variable (Table 6). For the total amount of foods and beverages reported, and the amount of all foods and energy-yielding

Table 4 Percentage in categories of socio-demographic variables by tertiles of energy density (ED) (kJ/g). NHANES III, 1988–1994

		ED 1 (all foods & beverages)			*ED 2 (foods & energy yielding beverages*			*ED 3 (foods only)*		
	All	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*
% Men	48±0.5	42±0.9	50±0.8	54±1.2	47±0.9	51±0.9	47±1.3	41±1.1	50±1.1	54±1.1
% ≤50 y	64±1.3	56±1.5	61±1.5	75±1.6	64±1.3	64±1.6	65±1.5	50±1.6	65±1.4	78±1.2
% Non-Hispanic White	78±1.1	87±0.8	78±1.2	68±1.8	75±1.2	77±1.5	82±1.2	76±1.4	77±1.5	81±1.2
% >12 y education	42±1.3	41±1.7	40±1.6	43±1.6	39±1.8	42±1.4	43±1.8	43±1.4	42±1.5	39±1.8
% Current smokers	28±0.8	33±1.2	25±1.4	24±1.0	30±1.6	26±1.1	27±1.0	19±0.9	28±1.2	36±1.3
% Supplement users	43±0.9	43±1.5	42±1.0	41±1.3	42±1.4	43±1.4	42±1.2	47±1.6	43±1.0	37±1.4
% History of chronic disease	29±0.8	34±1.1	29±1.0	23±0.8	30±1.3	29±1.0	27±0.9	35±1.0	28±1.0	23±1.1
% Trying to lose weight	34±0.9	40±1.3	33±1.1	29±1.4	35±1.2	33±1.0	34±1.5	39±1.4	33±1.0	31±1.4
% Consider self-overweight	54±0.7	59±1.1	53±1.3	50±1.1	53±1.0	52±1.2	57±1.3	52±1.1	55±1.0	55±1.1
% Reporting no recreational physical activity	22±1.0	20±1.4	22±1.1	22±1.2	21±1.1	21±1.2	22±1.2	23±1.4	21±1.2	20±1.2
% EI/BEE ratio <1.2	42±0.7	62±1.2	37±1.1	26±1.3	52±1.4	37±1.3	36±0.9	59±1.3	35±1.1	32±1.0
% BMI <25 kg/m^2	44±1.0	41±1.0	43±1.5	48±1.4	45±1.0	44±1.4	43±1.5	44±1.2	45±1.1	44±1.6
% BMI 25–29.9 kg/m^2	33±0.7	35±1.0	34±1.2	31±1.2	33±0.9	34±1.3	33±1.2	33±1.1	34±0.9	33±1.2
% BMI >29.9 kg/m^2	23±0.8	24±1.0	23±1.2	21±1.1	22±1.1	21±1.1	24±1.1	23±1.0	21±0.8	23±1.4

Table 5 Least-squares mean±s.e. of body mass index (BMI); odds ratios and 95% confidence interval of having a BMI of ≥25 kg/m^2; and β±s.e. associated with BMI, by tertiles of energy density (kJ/g). NHANES III, 1988–1994

	Tertiles of energy density				
	T1	*T2*	*T3*	*β±s.e.*[a]	P[b]
ED1 (kJ/g all foods and beverages)					
Men					
Mean±s.e.	26.9±0.2	26.7±0.2	26.5±0.2	−0.36±0.24	0.12
Odds ratio	1.0 (ref)	0.85	0.75		
95% CI	—	0.66–1.11	0.60–0.93		
Women					
Mean±s.e.	26.4±0.2	26.5±0.2	26.5±0.2	0.001±0.09	0.98
Odds ratio	1.0 (ref)	1.02	0.87		
95% CI	—	0.84–1.23	0.71–1.08		
ED2 (kJ/g all foods and energy yielding beverages)					
Men					
Mean±s.e.	26.7+0.1	26.5±0.1	26.9±0.2	0.47±0.22	0.03
Odds ratio	1.0 (ref)	1.02	1.18		
95% CI	—	0.89–1.17	0.94–1.48		
Women					
Mean±s.e.	26.2±0.2	26.5±0.2	26.7±0.2	0.42±0.14	0.0009
Odds ratio	1.0 (ref)	1.15	1.16		
95% CI	—	0.97–1.36	0.95–1.40		
ED3 (kJ/g of foods only)					
Men					
Mean±s.e.	26.6±0.1	26.5±0.1	27.0±0.3	0.37±0.19	0.02
Odds ratio	1.0 (ref)	1.07	1.32		
95% CI	—	0.86–1.33	1.05–1.66		
Women					
Mean±s.e.	25.9±0.2	26.6±0.2	27.0±0.3	0.40±0.18	0.02
Odds ratio	1.0 (ref)	1.25	1.35		
95% CI	—	1.06–1.47	1.07–1.69		

Adjusted for age (y), gender, race/ethnicity, level of education, smoking status, level of physical activity, currently trying to lose weight, history of disease (diabetes, hypertension, and MI). With addition of energy intake to the models above: the positive BMI trend associated with energy density remained significant for ED2 (men $P=0.05$; women $P=0.002$), and ED3 (men $P=0.03$; women $P=0.02$). [a]β±s.e: deattenuated regression coefficient associated with energy density (continuous) for predicting BMI as a continuous outcome. [b]Significance of the trend for predicting BMI as a continuous outcome with energy density as a continuous predictor.

beverages, the ratios of within- to between-person variance were less than one. Generally, the ratios of within- to between-person variance were smaller in women relative to men for most of the variables presented in Table 6.

Discussion

This cross-sectional study confirms the previously reported positive association of energy density with dietary energy and fat intake.[2,8,18,19] Given the patterns of reporting of

Table 6 The ratio of within- to between-person components of variance for energy density, amount of all foods and beverages (FD+bevs), amount of all solid foods and energy-yielding beverages (FD+Ebev), and amount of solid foods (FD), NHANES III, 1988–1994

	Energy density			*Amt. of foods and beverages*		
Ratio (within/between)	*ED1 (kJ/g)*	*ED2 (kJ/g)*	*ED3 (kJ/g)*	*FD+bevs (g)*	*FD+Ebev (g)*	*FD (g)*
All ($n=1037$)	1.34	2.05	1.53	0.58	0.67	1.26
Men ($n=506$)	1.62	2.42	1.54	0.80	0.86	1.94
Women ($n=531$)	1.16	1.78	1.54	0.48	0.67	1.00

ED1: kJ/g of all foods and beverages (FD+bevs) reported in the 24-h recalls. ED2: kJ/g of all food and energy-yielding beverages (FD+Ebev) reported in the 24-h recalls. ED3: kJ/g of all foods (no beverages) reported in the 24-h recalls. The components of variance were determined from two nonconsecutive, in-person 24-h dietary recalls.

nutrient-dense and low-nutrient-density foods with energy density, the inverse associations of micronutrient intake with all three types of energy density are in the expected direction, with slopes being steeper for ED2 and ED3 relative to ED1.

Irrespective of whether beverages contributed to the estimates of energy density, respondents reported lower amounts of all foods and beverages with increasing energy density (Table 2). An inverse association of energy density with weight of food has been reported by Stubbs *et al*,[18] but not Cuco *et al*.[8] However, the decline in amounts of foods and beverages with increasing energy density in the present study was not sufficient to prevent higher EIs, especially as the largest decline in amounts of foods reported was for fruits and vegetables while added fat intake increased with increasing energy density.

ED2 and ED3 were independent positive predictors of BMI in this cohort after adjustment for covariates potentially related with body weight and dietary reporting. It is unlikely that the contribution of dietary fat to increasing energy density is the primary reason for the association of body weight with ED2 and ED3, given the fact that the association of ED1 with BMI was not significant although its association with dietary fat was as strong as that of ED2 and ED3 with dietary fat. In a review, Yao and Roberts concluded that low-energy-density diets promote moderate weight loss in long-term studies.[19] However, Cuco *et al*[8] and de Castro[20] observed no association between BMI and energy density.

To our knowledge, this is the first study to provide within- and between-person estimates of components of variance for energy density of American diets. Generally, the magnitude of the ratio of within- to between-person variance for the three energy density variables was similar to the ratios reported for energy and macronutrients in other studies.[21] Considerable with-in person variance in energy density is reflected by within- to between-person ratios being greater than one. In view of the prevailing notion that food volume consumed may not change very much despite changes in energy density,[1–3] we had hypothesized that the within- to between-person variance in amounts of foods reported may be less than within- to between-person variance in energy density of diets. Our results are supportive of this hypothesis as the ratios of within- to between-person variance in total amounts of foods and beverages or amounts of foods and energy-yielding beverages (but not foods only) reported were smaller than one whereas these ratios for the three energy density measures were all greater than one.

Reporting of EIs that may be considered biologically implausible has been recognized as a problem in the NHANES III,[22,23] and other surveys.[24,25] Over half of those in the first tertile of each type of energy density had EI/BEE ratios of <1.2. Notably, however, a third of those in the second and third tertiles of each type of energy density also had EI/BEE ratio of <1.2. Body weight and attempting weight loss are also negative predictors of the ratio of EI/BEE. These associations may therefore be expected to attenuate the association of energy density with body weight. Nevertheless, we did find energy density to be a modest positive predictor of BMI in the present study, which suggests that true associations may be stronger than those reported here. The second recall subsample of NHANES III provided an opportunity to obtain an estimate of the extent of attenuation of regression coefficient for energy density. The regression coefficients for energy density after correction for measurement error were three to four times the uncorrected coefficient and, not surprisingly, the standard errors were also greater.

Finally, we note that our study is cross-sectional in nature and should be interpreted cautiously. Metabolic studies with their controlled variables are undoubtedly superior; this observational study merely reflects the nature of food selection behaviors reported by free-living individuals. For example, as has been pointed out by Poppitt and Prentice,[1] in an observational study such as ours, respondents with high EIs due to high energy density may be at energy equilibrium due to high energy requirements. Conversely, some respondents reporting low energy density diets may be striving for negative energy balance for weight loss. It is notable that nearly 50% of respondents in every tertile of each energy density variable considered themselves overweight and around 30% of those in the highest energy density tertile said they were trying to lose weight. Although we attempted to adjust for the effect of physical activity and attempting weight loss (along with other potential confounders) in our analysis, we cannot rule out residual confounding due to these or other unknown or poorly measured variables. Finally, we note that the NHANES III dietary recall did not provide information on plain drinking water (not bottled); therefore, the estimates of ED1 in our study are probably somewhat higher than might be expected if all water intake were part of the energy density estimate.

In conclusion, in the NHANES III, higher energy density was associated with higher intakes of energy, fat, and low-nutrient-density foods, and lower intake of fruits and vegetables but higher BMI. Decreasing energy-density of diets by including fruits and vegetables and moderating the intake of dietary fat and low-nutrient-density foods may help in decreasing EI and thus avoid positive energy balance.

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References

1 Poppitt SD, Prentice AM. Energy density and its role in the control offood intake: evidence from metabolic and community studies. *Appetite* 1996; **26**: 153–174.
2 Stubbs J, Ferres S, Horgan G. Energy density of foods: effects on energy intake. *Crit Rev Food Sci Nutr* 2000; **406**: 481–515.
3 Bell EA, Castellanos VH, Pelkman CL, Thorwart ML, Rolls BJ. Energy density of foods affects energy intake in normal-weight women. *Am J Clin Nutr* 1998; **67**: 412–420.
4 Rolls BJ, Bell EA, Castellanos VH, Chow M, Pelkman CL, Thorwart ML. Energy density but not fat content of foods affected energy intake in lean and obese women. *Am J Clin Nutr* 1999; **69**: 863–871.
5 Bell EA, Rolls BJ. Energy density of foods affects energy intake across multiple levels of fat content in lean and obese women. *Am J Clin Nutr* 2001; **73**: 1010–1018.
6 Rolls BJ. The role of energy density in the overconsumption of fat. *J Nutr* 2000; **130**: 268S–271S.
7 Stookey JD. Energy density, energy intake and weight status in a large free-living sample of Chinese adults: exploring the underlying roles of fat, protein, carbohydrate, fiber, and water intakes. *Eur J Clin Nutr* 2001; **55**: 349–359.
8 Cuco G, Arija V, Marti-Henneberg C, Fernandez-Ballart J. Food and nutritional profile of high energy density consumers in an adult Mediterranean population. *Eur J Clin Nutr* 2001; **55**: 192–199.
9 Cox DN, Mela DJ. Determination of energy density of freely selected diets: methodological issues and implications. *Int J Obes Relat Metab Disord* 2000; **24**: 49–54.
10 National Center for Health Statistics. *Plan and operation of the third national health and nutrition examination survey, 1988–1994*. US Government Printing Office: Washington, DC; 1994. (Series 1, 32, DHHS Publication (PHS) 94 1308.).
11 Third National Health and Nutrition Examination Survey (NHANES III). NHANES III Second Exam File Documentation, July 1999, http://www.cdc.gov/nchs/data/nhanes/nhanes3/EXAMSE-acc.pdf Accessed Feb 2003.
12 Kant AK. Consumption of energy-dense, nutrient-poor foods by adult Americans: nutritional and health implications. The Third National Health and Nutrition Examination Survey, 1988–1994. *Am J Clin Nutr* 2000; **72**: 929–936.
13 Institute of Medicine. *Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*, Pre publication copy. National Academy Press: Washington, DC; 2002.
14 SAS Institute Inc. SAS user's guide. Release 8.1. Cary, NC; 2000.
15 Research Triangle Institute. SUDAAN User's manual. Release 8.0. Research Triangle Park, NC 2001.
16 Korn EL, Graubard BI. *Analysis of health surveys* 1999. John Wiley and Sons, Inc.: New York, pp 19–23.
17 Armstrong BG. The effects of measurement errors on relative risk in regressions. *Am J Epidemiol* 1990; **132**: 1176–1184.
18 Stubbs RJ, Johnstone AM, O'Reilly LM, Barton K, Reid C. The effect of covertly manipulating the energy density of mixed diets on *ad libitum* food intake in pseudo free-living humans. *Int J Obes Relat Metab Disord* 1998; **22**: 980–987.
19 Yao M, Roberts SB. Dietary energy density and weight regulation. *Nut Rev* 2001; **59**: 247–258.
20 de Castro JM. Dietary energy density is associated with increased intake in free living humans. *J Nutr* 2004; **134**: 335–341.
21 Willett W. Nature of variation in diet. In: Willett W (ed) *Nutritional epidemiology*, 2nd edn Oxford University Press: New York; 1998. pp 33–49.
22 Briefel RR, McDowell MA, Alaimo K, Caughman CR, Bischof AL, Carroll MD, Johnson CL. Total energy intake of the US population: Third National Health and Nutrition Examination Survey, 1988–1991. *Am J Clin Nutr* 1995; **62** (suppl): 1072S–1080S.
23 Kant AK. The nature of dietary reporting by adults in the Third National Health and Nutrition Examination Survey, 1988–94. *J Am Coll Nutr* 2002; **21**: 315–327.
24 Pryer JA, Vrijheid M, Nichols R, Kiggins M, Elliott P. Who are the 'Low energy reporters' in the dietary and nutritional survey of British adults? *Int J Epidemiol* 1997; **29**: 146–154.
25 Livingstone MBE. Assessment of food intakes: are we measuring what people eat? *Br J Biomed Science* 1995; **52**: 58–67.